

Experimental Study on 340GHz Wave Material Penetration Attenuation Properties

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Abstract — The study on the properties of terahertz (THz) wave propagation in complex atmosphere always been key technology for variety terahertz communication modes, such as wideband & high-speed network, astro-satellite communication, altitude aero-craft communication, long distance vast data transfer, short range wireless security communication etc. There are four main factors make effects on the free space THz wave propagation attenuation, free space radiation loss, atmospheric gases loss, atmospheric particle scatter loss, material penetration attenuation, and quasi-multipath refraction loss effect. Among aforementioned factors, the first part free space radiation loss could be calculated by furies equation. The second part atmospheric gases loss is determined by wave frequency, weather condition and atmosphere composition. The third part atmospheric particle scatter could be neglected when compare with first two attenuation. While the fourth part material penetration attenuation is influenced by shield material's equivalent dielectric constant and its dimension. This paper discusses solid electronics based THz band T/R modules design, and the series 0.34THz wave material penetration attenuation experiment's diagram and its results.

Index Terms — Terahertz wave, THz T/R module, material penetration attenuation.

I. INTRODUCTION

Terahertz-wave has received considerable attention in both scientific and engineering communities for its higher communication speed, better imaging resolution and less harm medical care [1]-[2], is a new research focus which developed rapidly during last two decades. More recently, satisfactory achievements are obtained in designing terahertz source and detector equipments [3]-[4], there won't be "THz gap" between the microwave/millimeter wave and infrared/visible light any more.

The study on THz wave propagation in complex atmosphere properties is fundamental technology for THz radar and communication system. The THz wave propagation study focus on its gases loss, determined by wave frequency, weather condition and atmosphere composition. But the advancement of researches on terahertz-wave propagation attenuation properties is still poor. The main analysis method is given by ITU-R [5] which is only suitable for idea atmospheric (only take the oxygen, nitrogen and water vapor

into account). For real complex atmosphere, experimental method is preferred. Attenuation in THz wave transition involves wave penetrate material attenuation, especially for THz wave short range wireless communication situation, quantitatively experimental study are necessary.

While THz wave propagates in the atmosphere, there would be certain attenuation due to resonance with gas molecules, thus formed atmospheric attenuation characteristics. Between the atmospheric absorption lines there is some relatively minor atmospheric absorption bands distribute at the center frequencies of 35 GHz, 94 GHz, 118 GHz, 140 GHz, 183 GHz, 225 GHz, 340 GHz etc. [6], these minimum value attenuation peak are called atmospheric window. These bands will make great potential THz technology applications. In this paper, 340 GHz was selected as our THz wave material penetration's frequency.

II. SOLID THZ WAVE T/R MODULES DESIGN

Based on the solid electronics microwave and THz band components, refers to other THz experimental installations [7]-[8], THz wave propagation attenuation T/R modules were designed and assembled at EHF Key Laboratory of Fundamental Science, University of Electronic Science and Technology of China. The 340GHz $\times 36$ multiple THz wave transmitter chain and $\times 12$ LO subharmonic mixer ($\times 2$) based 340GHz wave receiver chain's photo and its diagram are shown in Fig. 1 and Fig. 2, respectively. As this 340GHz wave propagation attenuation experimental system shown in Fig. 3, the antennas assembled in T/R are aimed using optical collimator.



Fig. 1 340GHz THz wave T/R module photo

TABLE I
THz WAVE PROPAGATION IF POWER TESTED/CALCULATED COMPARISON

Distance of propagation	0.5	1.3	2.1	2.9	3.7	4.5	5.3	6.1	6.9	7.7	8.5	9.3	10.1
Tested IF Power (dBm)	-32.5	-40.5	-44.8	-47.5	-50.4	-51.7	-52.8	-54.6	-55.5	-56.6	-57.5	-58.8	-59.7
Calculated IF Power (dBm)	-33.49	-41.80	-45.98	-48.79	-50.92	-52.63	-54.07	-55.3	-56.38	-57.35	-58.22	-59.01	-59.74
Discrepancy (minus)	-0.99	-1.30	-1.18	-1.29	-0.52	-0.93	-1.27	-0.70	-0.88	-0.75	-0.72	-0.21	-0.04

$$P_{IF}(dBm) = P_i(dBm) + G_t(dB) + G_r(dB) - 92.4 - 20 \lg f(GHz) - 20 \lg d(km) - \gamma_a d(dB) - L_{mix} \quad (1)$$

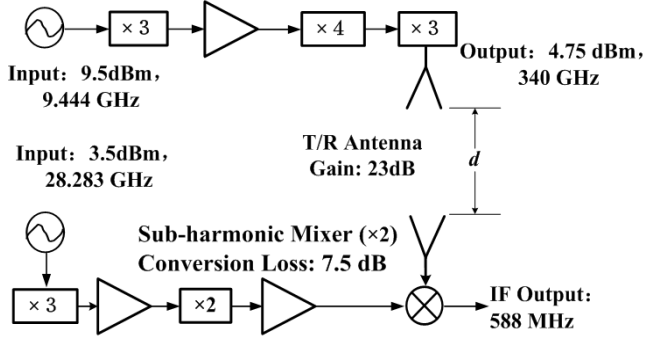


Fig. 2 The 340GHz THz wave T/R module's diagram



Fig. 3 THz wave propagation attenuation experimental system

Under barometric pressure of 102.65kPa, relative humidity of 68%, and temperature of 11 °C (according to the Recommendation ITU-R P.676-9, at this environment the atmospheric gases loss should be 15.47dB/km), series THz wave propagation attenuation experiments at different wave propagation distance from 0.5m to 10m are carried out. The comparison for tested and calculated IF power (can be derived by furies function, detailed using formula 1) as shown in Tab. 1. Series experimental results of IF power show good agreement with the calculation results, the power discrepancy less than 1.5dB.

III. EXPERIMENTAL ON 340GHz WAVE MATERIAL PENETRATION ATTENUATION

Series 340GHz wave material penetration attenuation experiments are carried out using aforementioned solid THz wave T/R modules. The distance between T/R antennas is fixed 4 m, and different materials are individually placed in the line of antenna aperture, 0.8m from receiver chain. Every wave penetration material is large enough to cover feedhorn antenna's central radiation area. This 340GHz wave material penetration attenuation experiment sketch map is shown in Fig. 4.

The THz wave material penetration attenuation experiment including different wave penetrate materials, detailed are foam with dimension 52.6cm×61.6cm×0.4cm, paper dimension 52.6cm×61.6cm×0.4cm, wood board 52.6cm×66.0cm×0.42cm, paper box 52.6cm×61.6cm×0.01cm, and 8cm thickness sofa chair, 14cm human body chest, 21cm cement wall, are shown in Fig. 5.

As the 0.34THz wave different material penetration attenuation experiment tested receiver IF power with corresponding wave propagation loss (with additional material insertion) comparison shown in Tab. 2, we get the foam has minimum penetration attenuation about 0.3dB, due to its low dielectric constant and tangent loss. While at the sofa chair and cement wall wave penetration situation, the received IF power level completely overcasted by background noise, show extremely wave propagation loss.



Fig. 5 THz wave material penetration attenuation experiment photo

TABLE II
340GHz WAVE DIFFERENT MATERIAL PENETRATION ATTENUATION COMPARISON

THz wave Material Penetrate	Air	Foam	Paper	Wood board	Foam & Paper & Wood board	Paper Box	Sofa chair	Human body chest	Cement Wall
Material Dimension		52.6×61.6	52.6×61.6	52.6×66.0	Same to former	56×49	-	-	-
Thickness (cm)	-	0.4	0.01	0.42	Same to former	10.5	~8	~14	~21
IF power (dBm)	-52.6	-52.9	-53.7	-61.5	-64.6	-66.5	≤-104	-91.2	≤-104
Propagation loss (dB)	0	0.3	1.1	8.9	12.0	13.9	≥51.4	38.6	≥51.4

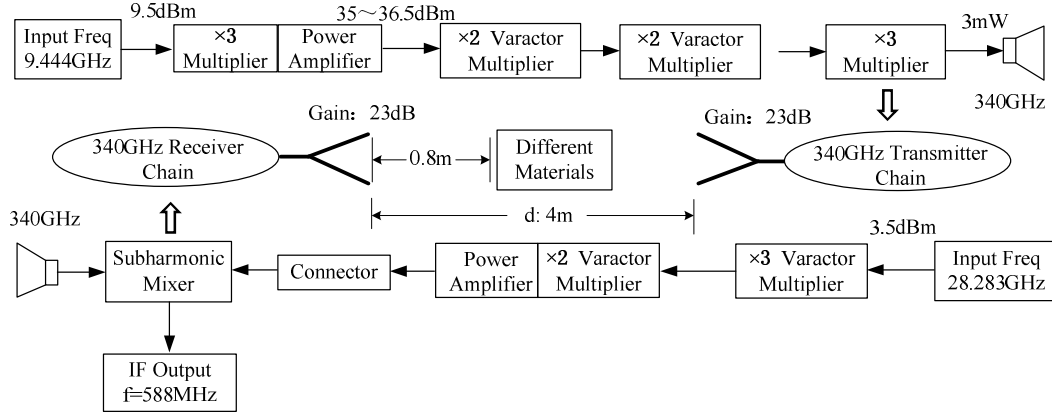


Fig. 4 THz wave material penetration attenuation experiment sketch map

IV. CONCLUSION

Among variety THz technologies & applications, the study on properties of THz wave propagation in complex atmosphere, especially quantitative get THz wave material penetration attenuation value is very important and fundamental. This paper discusses solid electronics based THz band T/R modules design, as well as the series 0.34THz wave material penetration attenuation experiment set and its results. The measured material penetration attenuation value would be useful reference for next generation THz communication technologies, wideband & high-speed network, astro-satellite communication, altitude aero-craft communication, long distance vast data transfer, short range wireless security communication etc.

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REFERENCES

- [1] Song, H. J. and T. Nagatsuma, "Present and future of terahertz communications", *IEEE Transactions on Terahertz Science and Technology*, vol. 1, no. 1, pp. 256-263, 2011.
- [2] Akyildiz, I. F., J. M. Jornet, and C. Han, "Terahertz band: Next frontier for wireless communications", *Physical Communication*, vol. 12, pp. 16-32, 2014.
- [3] Bulgarevich, D. S., M. Watanabe, M. Shiwa, et al., "A polarization-sensitive 4-contact detector for terahertz time-domain spectroscopy," *Optics Express*, vol. 22, no. 9, pp. 10332-10340, 2014.
- [4] Ollmann, Z., J. A. F. A. J. Hebling, et al., "Design of a high-energy terahertz pulse source based on ZnTe contact grating," *Optics Communications*, vol. 315, pp. 159-163, 2014.
- [5] International Telecommunications Union, Radiocommunications Bureau, "Attenuation by atmospheric gases", *Recommendation ITU-R P.676-9*, February 2012.
- [6] T.W Crowe, W.L Bishop, and D.W Porterfield, "Opening the Terahertz window With Integrated Diode Circuits, " *IEEE Journal of Solid-State Circuits*, vol. 40, no. 10, pp.2104-2110, 2005,
- [7] Meshkov, A. I. and C. D. L. Frank, "Laboratory measurements of dry air atmospheric absorption with a millimeter wave cavity ringdown spectrometer", *Journal of Quantitative Spectroscopy and Radiative Transfer*, vol. 108, no. 2, pp. 256-276, 2007.
- [8] Yang, Y., M. Mandehgar, and D. Grischkowsky, "Determination of the water vapor continuum absorption by THz-TDS and Molecular Response Theory", *Optics Express*, vol. 22, no. 3, pp. 4388-4403, 2014.